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MISSION G REQUIREMENTS FOR THE RTCC: NOMINAL ASCENT AND ABORT FROM DESCENT

By Veit Hanssen,
Lunar Landing Branch

(This document supersedes MSC Internal Note No. 67-FM-82 dated June 28, 1967)

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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MISSION G REQUIREMENTS FOR THE RTCC:

NOMINAL ASCENT AND ABORT FROM DESCENT

By Veit Hanssen

INTRODUCTION AND SUMMARY

This document describes the ascent and the abort from descent guidance laws necessary for the Real Time Computer Complex (RTCC) to simulate the ascent phase and to generate the required real time displays during the lunar landing mission.

This internal note replaces reference 1 and is based on the LUMINARY PROGRAM of the guidance system operations plan (GSOP) by MIT (ref. 2).

Since program change requests (PCR) were made after publication of reference 2, there are deviations from the GSOP due to updates which are included in this internal note. Any future updates will be documented as they occur. Although the guidance laws for nominal ascent are well defined and will probably experience only minor changes, considerable changes are expected in the abort guidance logic which is, therefore, only outlined in this document.

POWERED ASCENT GUIDANCE

The objective of the ascent from the lunar surface and from an aborted descent phase is to inject the spacecraft into a safe orbit which is also optimum for initiating the burns necessary for rendezvous with the command and service modules (CSM).

The powered ascent guidance laws are designed to provide full velocity, radial, and crossrange position control, which makes it possible to launch the LM into a CSM-coplanar or CSM-parallel orbit. It is left up to the astronaut to decide before liftoff how much out-of-plane distance to retain at the end of the injection phase.

Nominal Ascent

The nominal ascent program consists of three phases:

1. Preignition: In this phase the target parameters are initialized and the ascent guidance is cycled to compute thrust attitude for displays, assuming no vertical rise.

2. Vertical rise: The LM ascends along the radius vector till altitude rate and yaw attitude targets are met.

3. Ascent guidance: Guided burn phase from vertical rise to injection.

1. Preignition.- The necessary input parameters to initialize the preignition phase (P-12) of the ascent guidance are:

a. A state vector ($\underline{r}_c$, $\underline{V}_c$) of the CSM to define the target plane.

b. State vector of the ascent stage at ignition ($\underline{r}_{tig}$, $\underline{V}_{tig}$).

c. APS thrust (F), specific impulse (I_{sp}), and mass (M) of the ascent stage at ignition.

d. Time increment between APS tail-off and computation delay ($\Delta t_{tailoff}$).

e. Desired injection target parameters (R_D, Y_D, $\underline{V}_D$)

After initializing the targets, the crossrange component ($\underline{Q}$) of the target coordinate system is defined to be perpendicular to the CSM plane. $\underline{Q}$ is the only axis of the target coordinate system used in the ascent guidance, since the local vertical coordinate system defines the velocity control portion. Time to go (t_{go}) is set to a nominal value of 450 seconds and the vertical rise phase control flag (FLVP) is set to one.

2. Vertical Rise.- The vertical rise phase uses the standard ascent guidance equations. Its primary objective is to steer the spacecraft vertically from the lunar surface while performing a yaw maneuver (rotation around the X-body or thrust axis) so that at the beginning of the ascent guidance phase the spacecraft essentially performs a pitch maneuver, rotating around the vehicle Y-axis.

The vertical rise phase is initiated by defining the local vertical coordinate system and computing the crossrange distance in the target coordinate system.

The velocity to be gained ($\underline{V}_G$) is computed by subtracting the present velocity components from the desired rates. It is expressed in the local vertical system and does not include gravity effects.

The transformation matrix LVNB converts $\underline{V}_G$ from the local vertical to the vehicle body or navigation base coordinate system and the converted velocity-to-be-gained is used for displays during the RCS injection mode. The effective gravity is included in the velocity-to-be-gained vector in the APS ascent phase. The t_{go} computation is performed next. The equation for t_{go} (page 5, flow chart 1) is derived from a truncated series expansion of the exponential expression for t_{go} .

The guidance parameter computations based on the injection targets determine a thrust attitude which is used after the vertical rise phase. In the meantime this attitude steers the LM so that its Z-body axis is oriented within 5° of the reference vector $\underline{U}_{WDP}$ which is the horizontal component of the desired acceleration computed by the guidance equations. The unit thrust direction $\underline{U}_{FDP}$ which is based on the guidance parameter computations is updated during the vertical rise phase to point the LM axis along the radius vector.

The vertical rise phase is terminated when two conditions are met:

1. The Z-body axis has been yawed to within 25° of the plane in which the pitch-over maneuver takes place.

2. The radial rate is greater than or equal to 50 fps. When these conditions are satisfied, the vertical rise control flag is set to zero and the ascent guidance phase is initiated.

3. Ascent Guidance.- During this phase the thrust axis lies along the commanded acceleration vector ($\underline{a}_T$) and the vehicle attitude about the thrust axis is controlled by $\underline{U}_{WDP}$ such that the +Z-body axis will be in the downward direction. A seeming inconsistency in the computation of the crossrange guidance rate coefficient (D) is the distance Y which is in the target coordinate system, with all other parameters in the local vertical system. This inconsistency in coordinate systems is based on the small-angle assumption which is valid since the LM is never more than 2° out of the CSM plane.

When the time to go becomes less than 10 seconds the position control flag is set to one and the guidance rate coefficients B and D are set to zero. This procedure terminates the LM injection position control. At t_{go} less than 4 seconds the engine-off timer is initiated and the engine-off flag (FLENG2) is set to one. It should be noted that activating the 2 flags FLENG1 and FLENG2 does not determine the engine on and off times, since they only serve as "if" statements. No further guidance computations are made when t_{go} falls below 2 seconds and the previous guidance parameters are maintained until injection.

RCS Ascent Injection

This injection mode will be used if the APS shuts down prematurely (t_{go} less than approximately 1 minute). During RCS ascent FLRCS equals one and the guidance rate and attitude computations are bypassed. The velocity-to-be-gained ($\underline{V}_G$) is computed not compensating for the effective gravity, converted from the local coordinate system to vehicle body or navigation base coordinates, and displayed so that the astronaut manually completes the ascent maneuver. It should be noted that by neglecting the effective gravity, t_{go} computations are unnecessary and therefore not performed during the RCS injection mode.

Abort Guidance from Lunar Landing Maneuver

The abort can be performed by either the descent engine, the ascent engine, or descent plus ascent engines. The programs controlling these maneuvers are P70 for DPS and P71 for APS, where P71 can be initiated after DPS abort was attempted or partially performed or both. The lunar landing maneuver is subdivided into three abort zones:

1. DPS ignition up to 50 seconds into the burn.

2. Time from ignition (TFI) of 50 seconds to an altitude of 25 000 ft.

3. 25 000-ft altitude to landing on the lunar surface.

Zone 1.- If DPS abort (P-70) occurs within 50 seconds of the descent phase, program 70 is initiated which sets FLP 70 = 1, initializes the targets, and shuts the engine off. The average g routine is terminated followed by the computation of time of ignition (t_{ig}). The state vector extrapolated to t_{ig} is used to determine $\underline{V}_G$ using the ascent guidance but excluding the effective gravity component. With $\underline{V}_G$ computed, external ΔV defines the initial thrust attitude at ignition and program 40 monitors t_{go} and attitudes during the burn.

At APS abort (P-71) the DPS engine shuts down, staging occurs and the flag for initial computation cycle is set (FLIC = 1) and the ascent guidance is used for attitude maneuver and injection.

Zone 2.- Full thrust is maintained for DPS as well as APS when TFI is greater than 50 seconds, and the ascent guidance is entered after injection targets are initialized and the unit normal to the CSM plane is defined.

Zone 3.- If the altitude is less than 25 000 ft the vertical rise flag is set (FLVP = 1). The 25 000-ft altitude is added to the yaw error and the altitude rate targets of the nominal ascent phase. However, the vertical rise phase is terminated when either the altitude condition is satisfied or the nominal targets are reached.

Combined DPS and APS abort.- For APS injection after DPS abort was initiated or partially performed, staging occurs and t_{go} is set initially equal to 2 t_{go} because of the different thrust-weight ratio of DPS and APS. Following this t_{go} update, P-71 enters the ascent guidance.

ASCENT GUIDANCE COORDINATE SYSTEMS

The ascent guidance computations are performed in the local vertical and the target coordinate systems. It should be pointed out that the definition and significance of the target coordinate system (TCS) has changed during the years and is now almost a misnomer. Only one component (the axis normal to the CSM plane) is computed in the TCS to determine the crossrange distance. The local vertical system is used to define the velocity control portion.

Target Coordinate System

The target coordinate system (fig. 1) is referenced to the CSM plane and the initial LM position by:

$$\underline{Q} = \text{unit}(\underline{V}_c \times \underline{r}_c)$$

$$\underline{S} = \text{unit}(\underline{r}_o \times \underline{Q})$$

$$\underline{P} = \underline{Q} \times \underline{S}$$

where $\underline{P}$ and $\underline{S}$ are no longer used in the guidance equations.

Local Vertical Coordinate System

The local vertical coordinate system (fig. 1) is defined by:

$$\underline{U}_R = \text{unit}(\underline{r})$$

$$\underline{U}_Z = \text{unit}(\underline{U}_R \times \underline{Q})$$

$$\underline{U}_Y = \underline{U}_Z \times \underline{U}_R$$

where $\underline{r}$ is the current LM position vector and $\underline{r}_{CO}$ is the injection vector.

TABLE I.- DEFINITION OF FLOW CHART SYMBOLS

Symbol	Definition
a_H	Magnitude of required thrust acceleration
$\underline{a}_H$	Required thrust acceleration vector. This vector computes the thrust direction to achieve the injection targets R and Y ($\underline{a}_H = a_{TY}\underline{U}_Y + a_{TR}\underline{U}_R$).
a_T	Magnitude of available thrust acceleration. This value is compared to the required thrust and the difference of the thrust is burned into the downrange direction.
$\underline{a}_T$	Applied thrust vector ($\underline{a}_T = a_H + a_{TP}\underline{U}_Z$)
a_{TP}	Downrange thrust vector component (Z)
a_{TR}	Radial thrust vector component
a_{TY}	Crossrange thrust vector component (Y)
A, B, C, and D	Guidance coefficients
Δt	Integration stepsize
Δtc	Computation time delay between PIPA reading and sending of the commands
$\Delta t_{tailoff}$	Time increment used to correct t_{go} for APS tail-off
E_{YAW}	Yaw attitude parameter maintains the vertical rise plane until vehicle +Z axis is oriented within a .25° cone about the reference vector $\underline{U}_{WDP}$
F	Thrust magnitude
FLENG1	Engine-on flag

TABLE I.- DEFINITION OF FLOW CHART SYMBOLS - Continued

Symbol	Definition
FLENG2	Engine-off flag
FLIC	Initial computation cycle flag for abort programs P70 and P71
FLPC	Position control flag (no position control when set to 1)
FLRCS	Flag for RCS injection mode
FLVP	Vertical rise control flag
g	Acceleration of gravity on lunar surface (5.324548 ft/sec²)
g_{eff}	Effective gravity
$\underline{g}_p(t)$	Previous gravity acceleration vector at time t
h	Altitude above the landing site
$\dot{h}$	Altitude rate
I_{sp}	Specific impulse
K_T	Parameter which replaces the coefficient of the second order term of the series expansion of $e^{-\frac{V_G}{V_e}}$
M	Total mass of the spacecraft
$\dot{M}$	Mass flow rate
μ_M	Lunar gravitational constant
ω_M	Lunar inertial rotation rate
$\underline{Q}$	Unit vector perpendicular to the CSM plane

TABLE I.- DEFINITION OF FLOW CHART SYMBOLS - Continued

Symbol	Definition
$\underline{r}_c$	Radius vector of CSM
r_{LS}	Radius of landing site
$\underline{r}_{tig}$	Radius vector of ascent stage at ignition
LVNB	Transformation matrix which converts from local vertical to navigation base coordinate system
R	Radius magnitude $(R = r_{LS} + h)$
R_D	Desired injection radius
$\dot{R}$	Radial velocity
$\dot{R}_D$	Desired radial velocity
SMNB	Matrix to convert from platform to body coordinate system
τ	1. Initial mass to mass flow rate ratio
	2. Acceleration performance parameter when used in ascent guidance
t	Present time
t_2	Time interval before engine cut-off during which all guidance parameters are held at their last computed value
t_3	Time interval before engine cutoff during which no position control is exercised
t_{go}	Estimated time to ascent injection
t_{ig}	Time of ignition

TABLE I.- DEFINITION OF FLOW CHART SYMBOLS - Concluded

Symbol	Definition	
TFI	Time from ignition	
$\underline{U}_{FDP}$	Commanded thrust attitude vector	
$\underline{U}_{WDP}$	Desired reference window unit vector referenced to platform coordinates	
$\underline{U}_{R}$	Unit radius vector	
$\underline{U}_{Y}$	Unit crossrange vector	local coordinate system
$\underline{U}_{Z}$	Unit downrange vector	
$\underline{V}$	Inertial velocity vector	
$\underline{V}_{c}$	Velocity vector of CSM	
$\underline{V}_{D}$	Desired velocity vector at injection	
V_{e}	Exhaust velocity	
$\underline{V}_{G}$	Velocity-to-be-gained vector in local vertical coordinate system	
$\underline{V}_{GB}$	Velocity-to-be-gained vector in navigation base coordinate systems	
$\underline{V}_{tig}$	Velocity vector of ascent stage at ignition ($\approx$15.3 ft/sec for launch from lunar surface)	
Y	Crossrange distance	
Y_{D}	Desired crossrange distance at injection	
$\dot{Y}$	Crossrange velocity	
$\dot{Y}_{D}$	Desired crossrange velocity at injection	
$\dot{Z}$	Downrange velocity	
$\dot{Z}_{D}$	Desired downrange velocity at injection	

TABLE II.- CONSTANTS USED IN ASCENT PHASE[a]

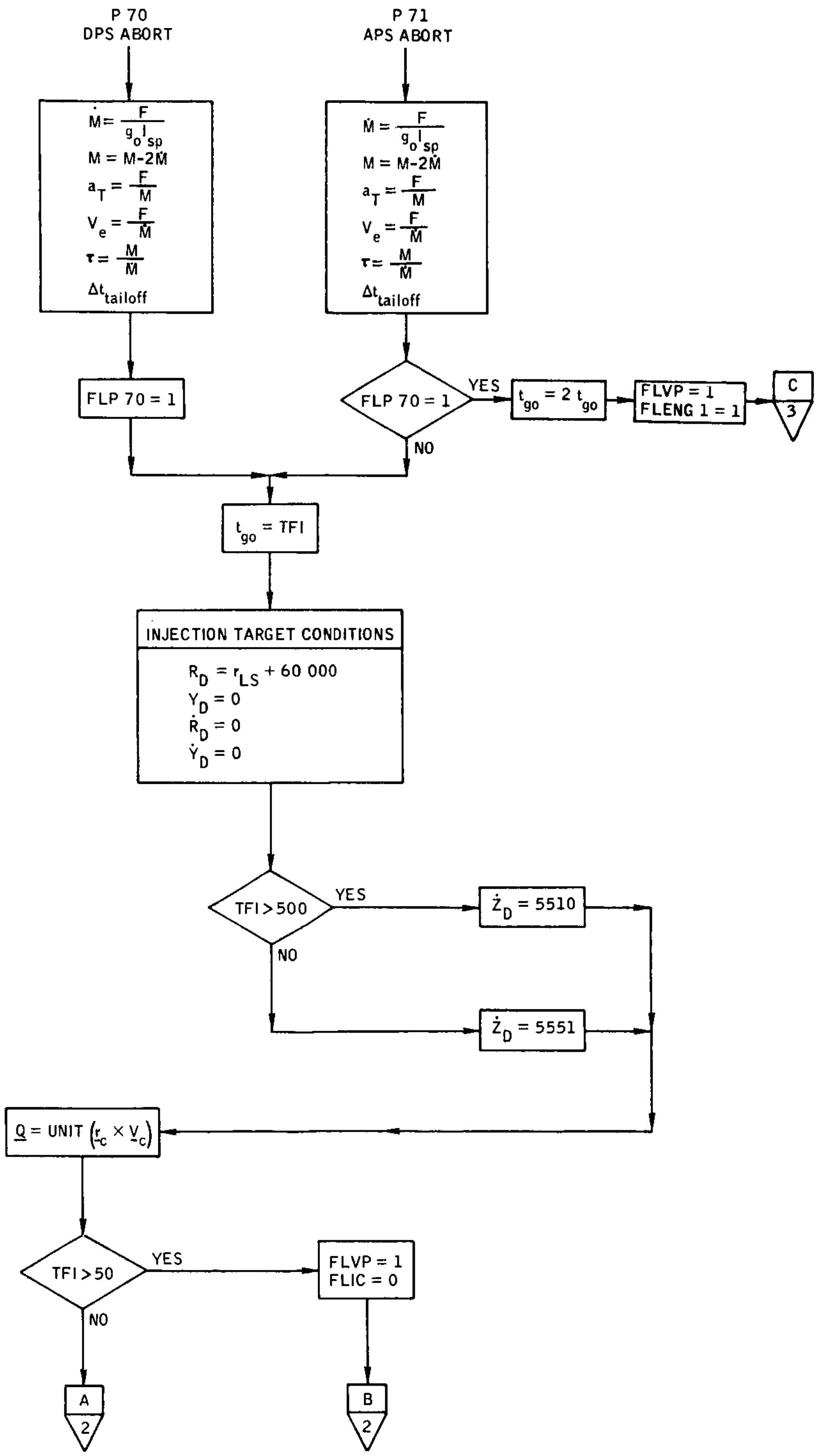
Constant	Value	Definition
a_T	10.5 ft/sec^2	initial thrust acceleration
Δt	2 sec	integration stepsize
$\Delta t_{tailoff}$	0.3 sec	
Δt_c	0.1 sec	
F	3500 lb	APS thrust
g_{moon}	5.3245 ft/sec^2	
I_{sp}	306 sec	APS nominal specific impulse
I_{sp}	303 sec	effective specific impulse
K_T	.5	
ω_M	$.26617 \times 10^{-5}$ rad/sec	angular velocity
R	5.7024×10^6 ft	radius of spherical moon
R_D	r_{LS} + 60 000 ft	radius at injection
$\dot{R}$	0 fps	radial rate at injection
r_{LS}	5.6975×10^6 ft	radius of landing site
τ	945 sec	initial mass to mass flow rate ratio
t_2	2 sec	time to go at which guidance parameters are maintained at last computed value

[a]The constants shown are representative for the ascent phase but should not be considered official values.

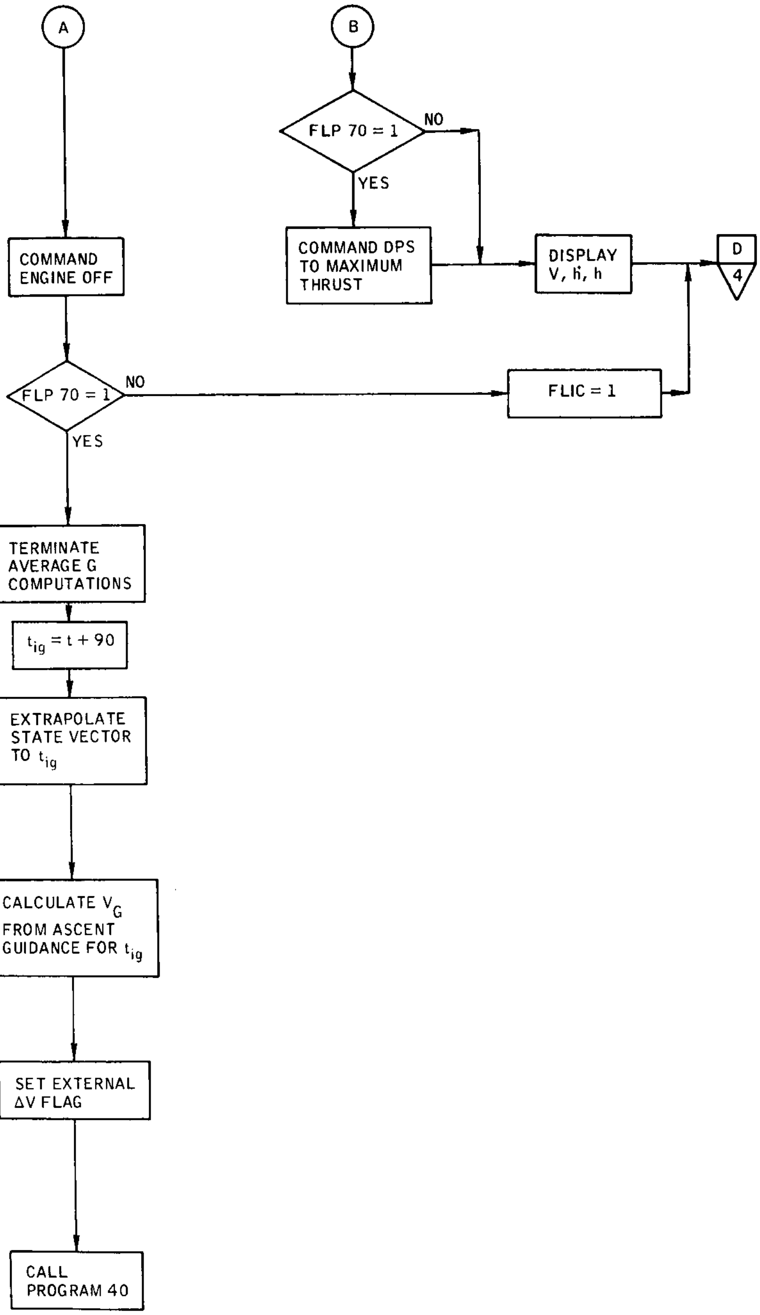
TABLE II.- CONSTANTS USED IN ASCENT PHASE[a] - Concluded

Constant	Value	Definition
t_3	10 sec	time to go at which spacecraft loses position control at injection
μ_M	1.731400×10^{12}	lunar gravitational constant
V_e	9850 fps	exhaust velocity
W_A	10733 lb	ascent stage at liftoff
W_{PROP}	5044 lb	usable propellant
Y_D	0 ft	crossrange distance at injection
$\dot{Y}_D$	0 fps	crossrange rate at injection
$\dot{Z}_D$	5510 fps	downrange velocity at injection

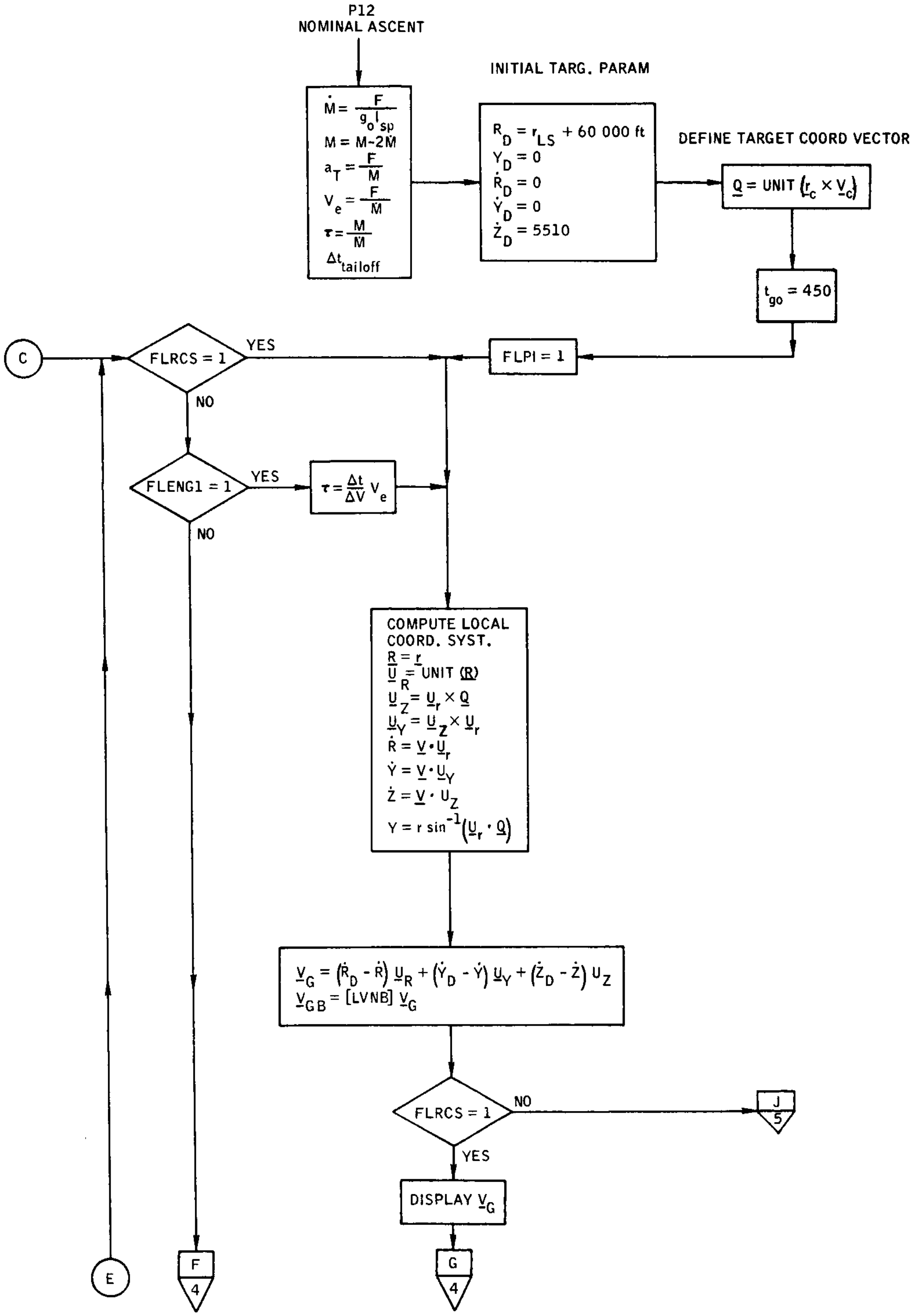
[a]The constants shown are representative for the ascent phase but should not be considered official values.



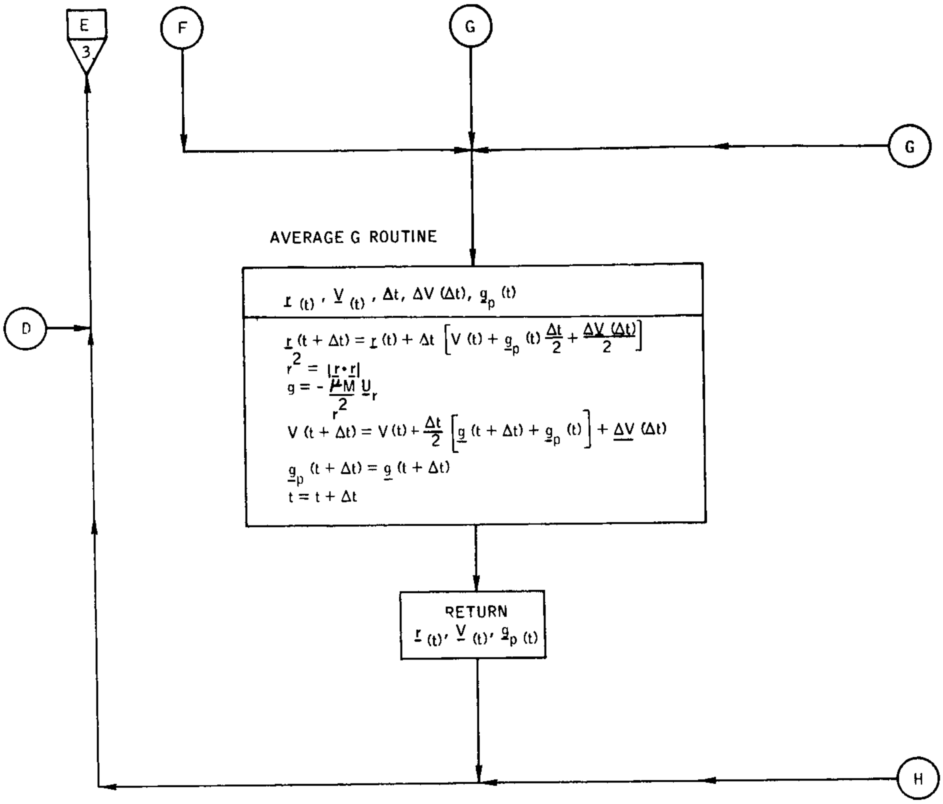
Flow chart 1.- Nominal ascent and abort from descent guidance.



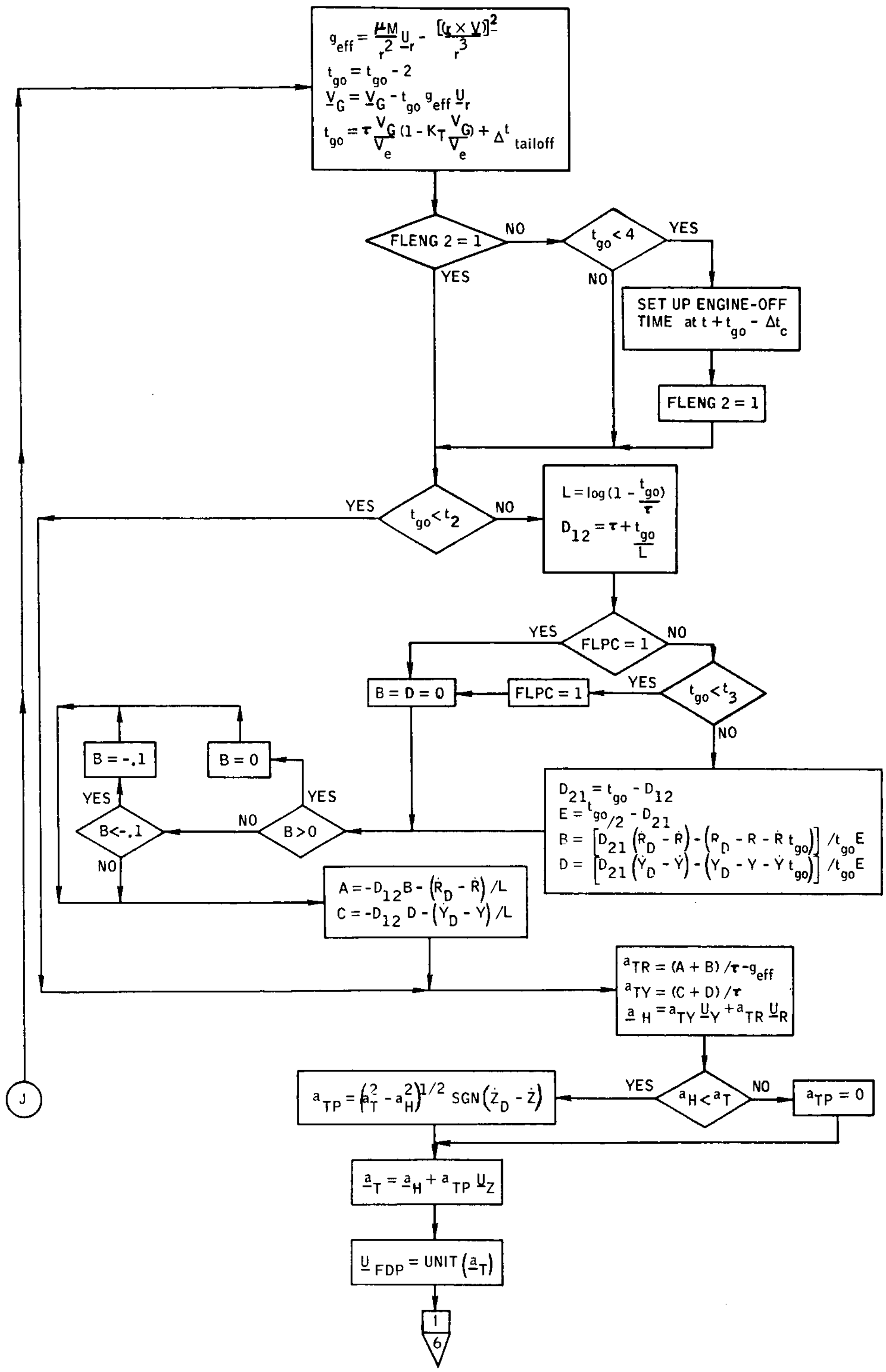
Flow chart 1.- Nominal ascent and abort from descent guidance.- Continued.



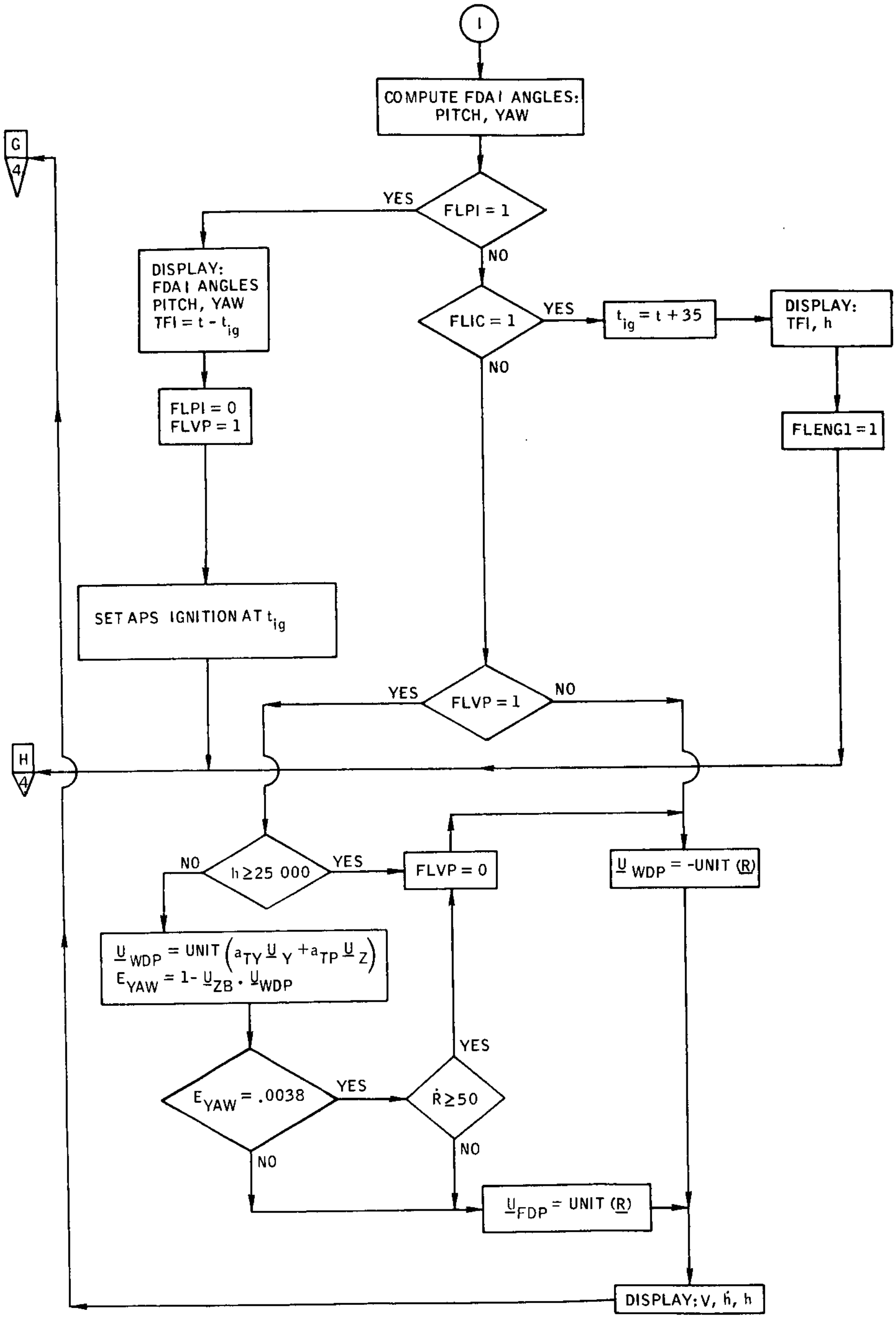
Flow chart 1.- Nominal ascent and abort from descent guidance.- Continued.



Flow chart 1.- Nominal ascent and abort from descent guidance.- Continued.



Flow chart 1.- Nominal ascent and abort from descent guidance.- Continued.



Flow chart 1.- Nominal ascent and abort from descent guidance.- Concluded.

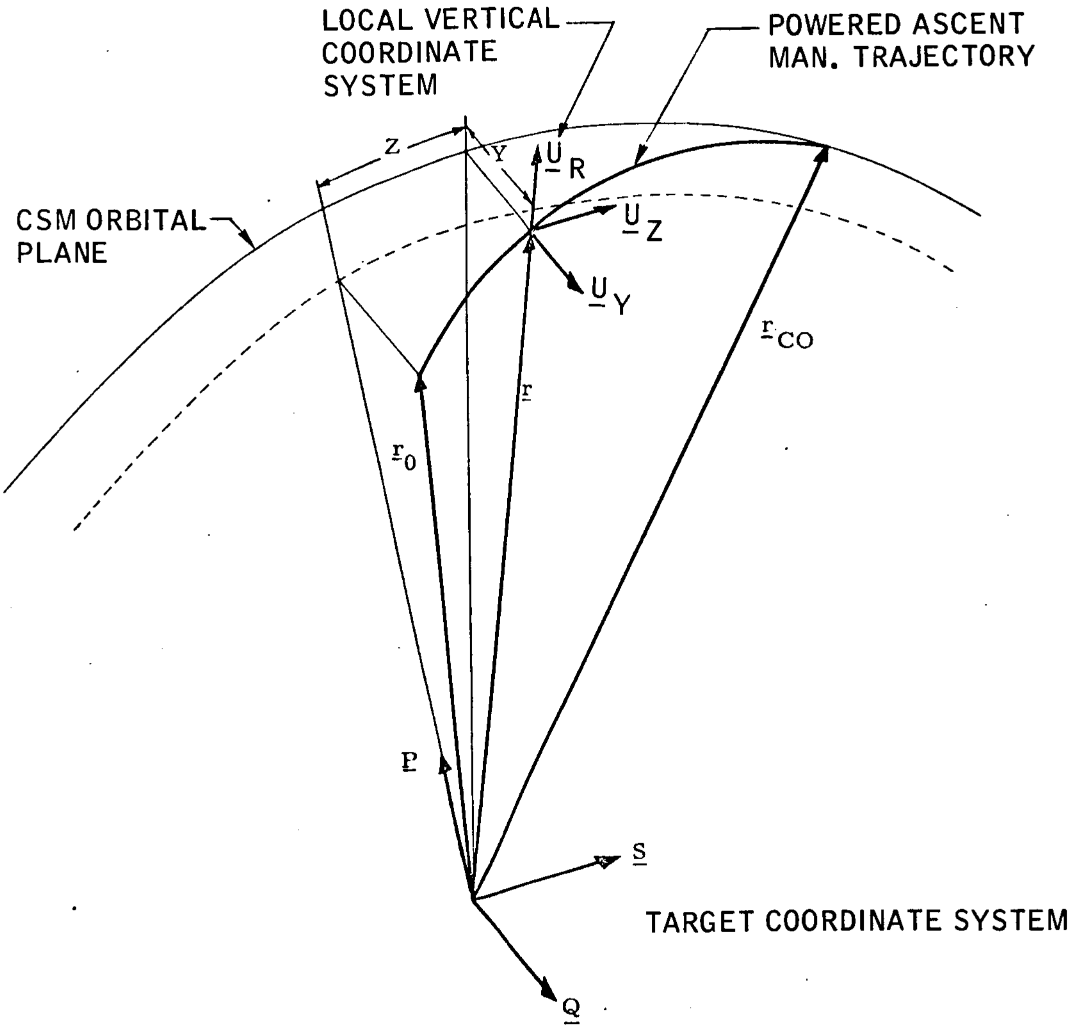


Figure 1.- Powered ascent guidance coordinate systems.

REFERENCES

1. Fridge, Ernest M.; and Yencharis, Jerome D.: AS-503A/AS-504A Requirements for the RTCC: Powered-Flight Simulations. MSC Internal Note 67-FM-82, June 28, 1967.

2. MIT: R-567, Guidance System Operations Plan for Manned Lunar Landing Missions, Section 5. MIT Type 1 Document, January 1968.